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Design of DOI PET detector modules using phoswich and SiPMs: First Results

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***Abstract*– PET detector modules that implement depth of interaction information reduce uncertainties about the actual line-of-response after positron annihilation. This, in turn, has an effect in the spatial resolution and uniformity across the field of view of the reconstructed image. It also has an effect on the system sensitivity since it enables the use of thicker crystal with respect to a non-DOI system without deteriorating significantly the spatial resolution. In this work we evaluate a DOI detector design based on a scintillator phoswich of two types of pixelated crystals with different time decay constants. A matrix of silicon phomultipliers (SiPM) was coupled to this crystal array without any light-guide, and its outputs were connected to an anger logic type of charge divider which outputs were buffered using a trans-impedance amplifier. These position signals were digitized using charge-to-digital converters, and the time decay constant of the crystal of interaction was measured using a delayed charge method. Previous works reported in the literature have demonstrated that this scheme for DOI PET detectors produce very good results in terms of spatial and energy resolution; however, the replacement of PMT with a SiPM matrix introduces some uncertainties that required further study. SiPM have demonstrated their good imaging capabilities when used with pixelated crystal scintillators, and their good timing performance allow us to predict that the DOI resolution was not going to be a problem with this technology. In this work we present quantitative results that assess the goodness of these detectors for its use on small-animal PET scanners.**

I. Introduction

PET detector modules that implement depth of interaction information reduces uncertainties about the actual line-of-response after positron annihilation. This has an effect in the spatial resolution and uniformity across the field of view of the reconstructed image. It also has an effect on the system sensitivity since it enables the use of thicker crystal with respect to a non-DOI system without deteriorating significantly the spatial resolution [1, 2].

We want to evaluate a DOI detector design based on silicon phomultipliers (SiPM) and a scintillator phoswich of two types of pixelated crystals with different time decay constants. For this purpose a matrix of SiPM [3] is coupled to this crystal array and its signals are connected to an anger logic type of charge divider [4]. These position signals are digitized and the time decay constant of the crystal of interaction determines the crystal of interaction.

Previous works reported in the literature have demonstrated that this scheme for DOI PET detectors produce good results in terms of spatial and energy resolution [5]; however, the replacement of the PS-PMT with a SiPM matrix introduces some uncertainties that required further study even though SiPM have demonstrated good imaging capabilities when used with pixelated crystal scintillators [6], and good timing performance [7-9].

This work presents an initial performance assessment of these detectors for its use on small-animal PET scanners.

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II. Material and Methods

The 3x4 crystals matrix is a pixelated scintillator phoswich comprised of a front layer of cerium-doped lutetium–yttrium orthosilicate (LYSO, 40 ns decay constant) and cerium-doped gadolinium orthosilicate (GSO, 60 ns decay constant) in the back layer, with reflectors between them that distributes the light on the SiPM matrix uniformly. The coupling with the SiPM is made with optical grease. A last row of dummy crystals was used to form a 4x4 array needed for the mechanical assembly.

Two types of silicon PMs were used: Hamamatsu MPPC-33-2_2-50 5900 6mm x 6mm (2x2 array), 3600 microcells, 50 μm cell size, PDE=50%, and SensL SPM array 15.8mm x 15.3mm (4x4), 3640 microcells, 50 μm cell size, PDE=10-20%

A. Data acquisition

The detector outputs were connected to an anger logic type of charge divider which outputs were buffered using a trans-impedance amplifier [10]. Individual pulses were recorded with a digital oscilloscope (1 GHz BW, 2 Gs/s). Complete event signals were digitized using a charge-to-digital converter; and the time decay constant of the crystal of interaction was measured using a delayed charge integration method.

Data transmission is done using an USB 2.0, and a FPGA is used in several acquisition tasks such as event detection, managing data from analog-to-digital converters or processing those data in real-time. From the six ADC channels one is used as a TDC (Time-to-Digital Converter) for fine time-stamp of the events, and a second one does the delayed charge integration used in the phoswich crystal identification [11].

Field-flood illumination is done using a using a 22Na radioactive source, and the pencil-beam used to scan the detector sideways was formed by collimating a 18F source using lead (Pb) shields and electronically setting in coincidence the SiPM-based detector with a fast PMT coupled to a lutetium based scintillator crystal.

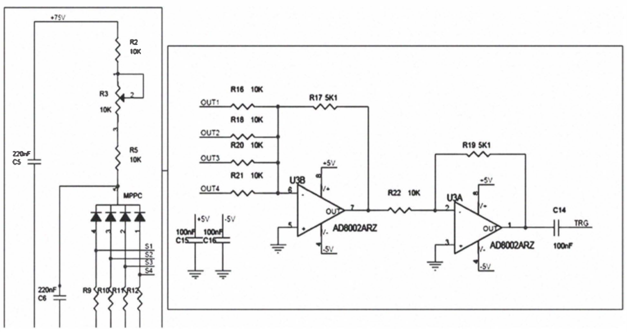

Fig. 1. Readout electronics based on the Analog Devices AD8002 (600MHz bandwidth and 1200 V/ms slew rate) current feedback amplifier. Capacitive coupling was optional.

III. Results

Pulse shape for single crystals clearly (Fig. 2) shows two different decay times, what indicates that the timing performance of these devices preserves the phoswich information.

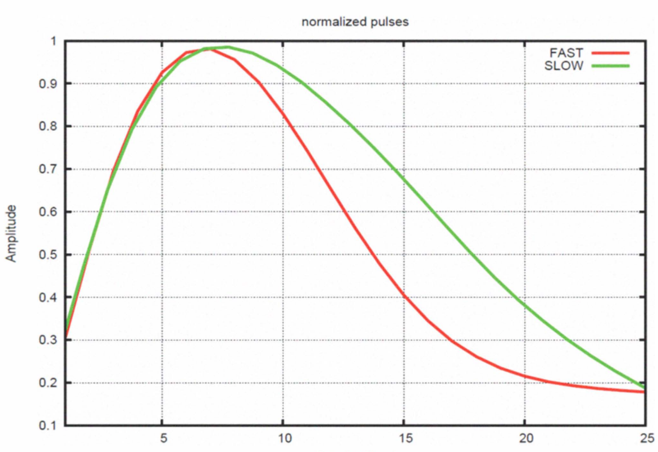

Fig. 2. Average of 1000 LYSO pulses (red) and 1000 GSO pulses (green). Integration windows for the total and delayed energy were derived from these recordings

The corresponding phoswich diagram for single crystals depicts two different clusters easy to segment (Fig. 3).

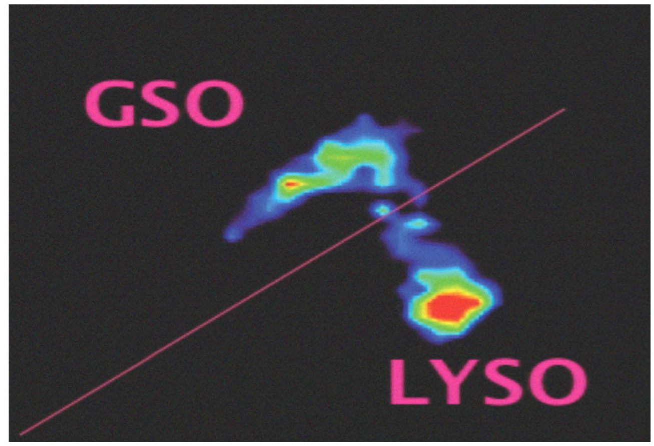

Fig. 3. Enlargment of the photopeaks area of the phoswich image of a single crystal for a field flood illumination of the array. Axis are total energy (X) and delayed energy (Y) for a selected single pixel from the matrix. Total integration time was 200 ns, delay was 140 ns

Individual phoswich elements can be differentiated in the field-flood images (Fig. 4) and the peak-to-valley ratio is bigger than ten (Fig.5).

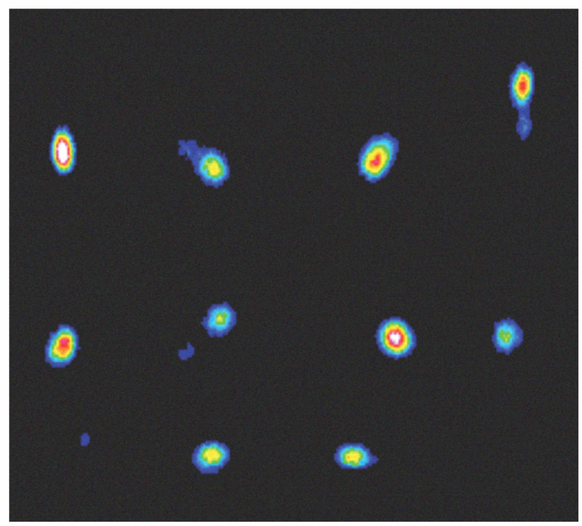

Fig. 4. Field-flood illumination of the complete detector assembly (only 3x4 pixels are in the FOV).

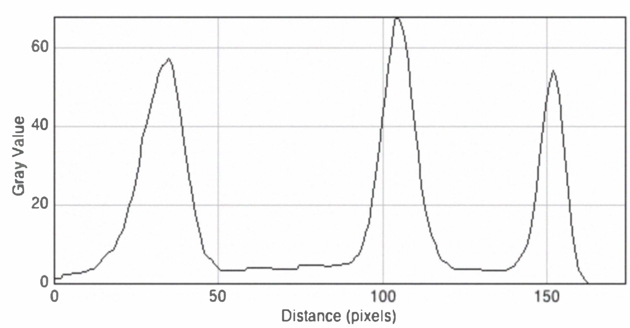

Fig. 5. Vertical profile across the central crystal column.

Phoswich diagrams for the whole array (Fig. 6) also show that the two scintillator layers can be identified even after the averaging introduced in the assembled spectrum due to the different gains of each crystal. Note that in this figure the axis are different than in Fig. 3.

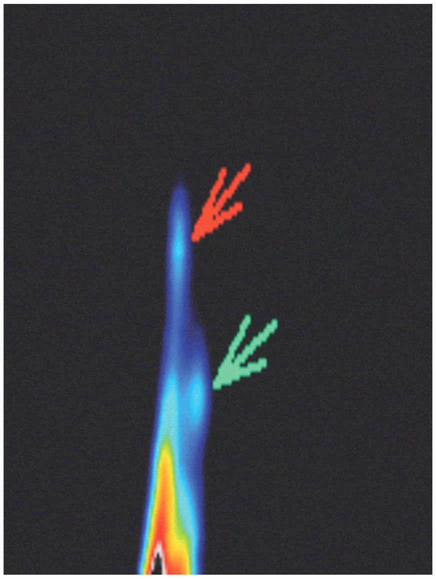

Fig. 6. Diagram phoswich photopeak identification for the complete array: GSO crystal (green arrow) and LYSO crystal (red arrow). (X) axis is the normalized delayed energy, and (Y) is the total energy.

IV. Conclusions

In these tests SiPM have demonstrated their good imaging capabilities when used with pixelated crystal scintillators, and their good timing performance in terms of light pulse shape preservation, which allows predicting that the DOI identification based on delayed charge integration method is not going to be a problem with this technology. In this work we present first quantitative results that suggest that the SiPM could be a replacement to PS-PMTs for high resolution DOI PET detectors.

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